

# Dilemmas and Pathways to Dealing with Flood Problems in Twenty-First Century China

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**Abstract** With more than 60 percent of China's 1.34 billion population, about 50 percent of its most productive arable land, and the world's second largest and rapidly growing national GDP exposed to flooding of various kinds, China has an intractable flood problem. Envisioning potential impacts of climate change and continued intensification of floodplain development driven by rapid industrialization and urbanization, it is very likely that China will see a continued increase of exposure to floods this century. This overview article outlines and discusses fundamental dilemmas, plausible pathways, and key options for managing future flood risks in China in the context of rapid socioeconomic transition and climate change. Fundamental dilemmas are the embedded difficult trade-off choices, from balancing economic development with flood vulnerability reduction, to coordination and cooperation among increasingly diverse actors and across scales. Among plausible pathways, this article argues that a resilience strategy for managing flood risk is desirable. It would require human adjustment to flood, not by aiming for full protection and control but by adjusting our use of floodplains, integrating and experimenting with a wide range of flood risk management options, so that a dynamic balance is maintained between exposure and coping capacity and flood risk is contained at an acceptable level. Embracing variability and uncertainty lies at the heart of such a flood resilience centered paradigm. Reducing the flood toll cannot be had without trade-offs in economic development, food production, and agricultural productivity.

**Keywords** China, flood risk dilemmas, flood management pathways, flood risk management, flood resilience strategy

## 1 Introduction

Globally, recent decades have seen rapid increases in losses due to natural disasters (UNISDR 2009). Despite progress in science and technology and the tremendous amount of attention and investment, vulnerability to flood disasters, in China and the world alike, has increased. There is a range of explanations for such a great paradox (White, Kates, and Burton 2001; IPCC 2011). Yet, in the case of flood losses, this also

reflects the fundamental dilemma concerning flood risk management—the use and development of floodplains, while increasing the exposure to floods, are also vital for improving the general well-being of the populations and the economy of regions. The problem lies in the imbalance between exposure and coping and adaptive capacity. While coping capacity has also increased as countries have developed and both economic conditions and governance have improved, the pace has not been sufficient to compensate for the increase in exposure and vulnerability, particularly in rapidly emerging economies (UNISDR 2009).

Into the twenty-first century, there has been a worldwide significant shift in the management of risks associated with river and coastal flooding (Harvey, Evans et al. 2009; Harvey, Thorne et al. 2009; Green 2010). The essence of this shift is moving away from control-oriented flood defense to a risk-based, more holistic approach, with an emphasis on system perspective and sustainability. There is now a strong recognition, at least within the flood management community, that sustainable flood mitigation solutions have to be achieved through integrated actions (White 1994; APFM 2003; Cheng 2005; UNDP 2004; UNISDR 2004). This shift can be traced back to the work of geographer Gilbert F. White and others who demonstrated convincingly the inadequacy of relying on engineering solutions alone to address flood problems. It was White who first argued that, instead of trying to control nature, society needs to learn to live more compatibly with the natural occurrence of floods (White 1945; Burton 1962; Burton, Kates, and White 1978).

Embracing variability and uncertainty lies at the heart of the new flood resilience centered paradigm. The fundamental and arguably most difficult change required is therefore for decision makers and society at large to accept that it is neither possible nor necessary to control all floods. A resilience strategy for managing flood risk would require human adjustment to flood, not by aiming for full protection and control but by adjusting our use of floodplains, integrating and experimenting with a wide range of flood risk management options, so that a dynamic balance is maintained between exposure and coping capacity.

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China has an intractable flood problem. Each year, China suffers billions in economic losses and hundreds to thousands of lives are lost. Looking into the future, the country's difficult flood problem is only going to become worse. By the middle of this century, China will be home to about 1.6 billion people and more than 70 percent of them will be living in cities on floodplains (Cheng 2008). If the current trends of socioeconomic development continue, China will become the largest economy in the world and close to 80 percent of its productivity will come from floodplains. Per capita GDP will at least quadruple its current value; thus the assets on the floodplains will keep on increasing exponentially. It is likely that climate change will also significantly increase both the intensity and the frequency of extreme weather events, making floods an even more severe threat (Shankman, Davis, and Leeuw 2009; IPCC 2011).

For millennia, China's flood management experience has predominantly centered on controlling floods through engineering structural measures, either by blocking or channeling the floodwater. For example, the legislative and institutional apparatus for flood management, such as the Flood Control Law of 1998, focuses primarily on controlling flood hazard and lacks almost completely any component of floodplain management, such as flood risk zoning and land-use regulation. To this day, there is little or no regional-scale floodplain planning (Shankman, Davis, and Leeuw 2009). Flood zoning and land-use planning measures in flood management remain at an embryonic stage (Cheng 2008).

As has been concluded by many analysts and observers, the increasing trend of flood losses, particularly during the 1990s, has stimulated a profound reflection and rethinking of flood management strategies in China (Cheng 2006; Harvey, Thorne et al. 2009). In 2003, the Ministry of Water Resources of China proposed to redirect flood prevention from flood control to flood management, which has led to a major institutional shift to enhancing understanding about interconnected systemic issues and risk awareness. Flood prevention work has thus shifted from attempts to eliminate floods to building capacity to live with and endure floods (GHD and IWHR 2006; Cheng 2008).

Three main aspects are central to this shift of overall strategy in flood management. First is the shift away from the notion of "full protection" to an acceptance that the flood defense system will have to be balanced with social and economic development on floodplains. Second is the shift from managing flood hazard to emphasizing the importance of floodplain management. Third is the approach to manage floods not only as a risk, but also as an opportunity and resource. This has involved a paradigmatic change from flood control to (ideally) controlled flooding. It is clear that this shift in China is consistent with and a reflection of an overall global rethinking and paradigm shift on humans' relationship with floods and how flood risk can be managed in a changing climate and an increasingly interconnected world. Embracing variability and uncertainty lies at the heart of such a new flood management paradigm.

While the shift in China from preventing flood events to managing flood risks is a fundamental step forward towards a more holistic and comprehensive approach to live with flood risk, it does not guarantee in any sense that the flood problem will be resolved. Fundamental dilemmas are entangled with flood problems in China. To what extent can vulnerability be significantly reduced without interfering with the progress in economic gains and improvements in overall well-being? To what extent are politicians as well as the general public prepared to accept the major investments that will be required for the transition to a more robust resilience strategy? What is an acceptable level of flood risk and how should it be determined? Understanding the fundamental dilemmas is essential for addressing the questions that are critical for devising a strategy that charts a path through complex science-policy-practice interfaces and leads towards balanced, coordinated, and sustainable solutions.

The following two sections outline three fundamental dilemmas and three plausible scenarios of future pathways for managing flood risk in China. The article concludes with some remarks on the importance of embracing uncertainty in developing a resilience strategy.

## 2 Three Fundamental Dilemmas for China

A dilemma refers to a situation that requires a choice between options that are or seem equally unfavorable or mutually exclusive (American Heritage Dictionary). In essence, dilemmas are about making choices between alternative courses of action in which, in this case, trade-offs between risks and benefits are central and inescapable. Thus these dilemmas, by definition, defy solutions that appeal to all parties in that trade-offs exist in the course of achieving the resolution of desired societal wants or needs and these trade-offs must be balanced and negotiated.

The contextual environment for flood risks in China is now undergoing rapid change due to global processes (such as globalization and global environmental change) and regional and local processes (such as rapid urbanization, industrialization, and social transformation). Deeply embedded in this changing context, China faces a set of fundamental dilemmas for managing its flood risk, where trade-offs are inevitably contentious yet must be made in balancing complex relationships between risk reduction and economic development.

### 2.1 "Space for Water" versus "Space for People"

By definition, floodplains are the land that could and would be flooded periodically. When floodplains are settled and developed, the competition for space between people and water (that is, floods) becomes the basic dilemma. With more than 60 percent of its 1.34 billion population, about 50 percent of its most productive arable land, and close to

80 percent of the world's second largest and rapidly growing national GDP depending on floodplains, China faces intense competition between "space for water" and "space for people"—a fundamental dilemma between flood risk reduction and economic development on China's floodplains.

Nothing illustrates this dilemma more vividly than the so-called flood detention / retention area dilemma in China. Since the 1950s, an important part of China's flood management strategy has been to establish designated flood detention and retention zones to accommodate excessive waters. Currently, China has 98 such designated zones, with a total area of 35,000 km<sup>2</sup> and a total storage capacity of about 100 billion m<sup>3</sup>. Yet, through decades of encroachment these zones now contain about 2 million hectares of cropland and more than 17 million people (Cheng 2005; Cheng 2008). Thus, in order for the designated zones to serve the intended flood adjustment function, China will have to find a way to resettle the 17 million people and change the ongoing settlement processes—not an easy dilemma to solve.

Furthermore, this difficult dilemma in all likelihood will only get worse. Within the floodplains, intensification of human activities and a shifting spatial concentration of both people and wealth will significantly increase China's exposure to floods in the coming decades. While China's population growth has slowed considerably due to the strict implementation of the one-child policy, its total population will likely grow to about 1.6 billion around 2030 before declining gradually. China will add the equivalent of the current U.S. population in the next twenty years, and the majority of this population increase will live in cities on floodplains. Even if this population intensification occurs at a slower pace than that experienced historically, the economic intensification on floodplains in the coming decades will still be tremendous and constitute a real challenge in Chinese history. It will shift the nature of the flood problem in China from a predominantly agricultural concern to an urban concern and food security threat.

This fundamental dilemma underlies the general trade-off between flood risk reduction and economic development—it is simply not possible to have both. Choices must be made, ranging from complete retreat from floodplains to bearing the full flood losses for economic gains. Anything in between is caught between irreconcilable goals. So far, the primary approach that China has employed to address this dilemma is to protect development from floods by extensive construction of flood defense infrastructures. Despite major investments, economic losses continue to increase (Cheng, Wu, and Wang 2004). The rising flood damage trend highlights the rapid increase of vulnerability due to intensification of floodplain development and assets accumulation. It also indicates the inherent limitations of the engineering approach.

Increasing flood vulnerability is essentially the result of the rapid development of China's floodplains. Vulnerability reduction thus requires a much broader approach to deal with the trade-offs between economic development and flood risk reduction in the context of multiple stresses and multiple

vulnerabilities. Despite rapid development in recent decades, hundreds of millions of people in China are still living in poverty. Environmental deterioration and ecological destruction are widespread and devastating (Liu and Diamond 2005). China faces the dilemma of the need to achieve overall livelihood improvement while seeking to build societal resilience against floods. Flood risk reduction therefore will have to be integrated into or balanced against the broader context of poverty reduction, environmental and ecosystem management, improving overall well-being (longevity, income, education, health, and so forth), and sustainable development. It is a challenge that flood managers would like to avoid.

## 2.2 Cooperation versus Conflict

The second fundamental dilemma in flood risk management that China faces lies in the governance challenges where coordination and cooperation are central for resolving the inevitable conflicting interests among regions and social groups. Cooperation is a key potential resource needed for any viable future flood management approach. At the same time, economic decentralization, market reform and privatization, and growing regional and social disparities make cooperation increasingly difficult to achieve.

Reducing vulnerability is a complex task that involves an increasingly diverse range of actors, both public and private, concerning land-use decisions and the built environment (Hall 2008). All measures designed to reduce flood risks will have different spatial and social impacts. They typically involve spatial conflict (upstream and downstream, left and right riverbanks, urban and rural) and social tensions (among social groups, priorities, and so forth), thus demanding an enlarged capacity for balancing, coordination, and cooperation among regions and social groups. At the same time, with economic decentralization, the centralized command and control system in China has been weakened in its ability to "force" coordination and cooperation among regions and different stakeholders. The maneuvering space for coordination and cooperation is becoming increasingly small, while the actors and interests are becoming ever more diverse. A combination of balanced government and market instruments has yet to appear on the horizon. China still lacks the required and enabling institutional infrastructure. In the current Chinese flood management system, the roles of the various actors remain opaque and ill-defined and constitute major obstacles for effective coordination and cooperation.

The coordination and cooperation dilemma makes the flood risk management goal-setting process more challenging. What would be an acceptable level of risk reduction against which flood risk management should be measured, monitored, and evaluated? Setting such a goal is critical yet extremely difficult and contentious. An acceptable level of flood risk will always be problematic and uncertain since it rests on a wide range of processes, factors, and conflicting values. Often, as people get richer, their demand for safety correspondingly increases. But the trade-offs between safety

and wealth are highly sensitive. Making people safer and less rich may not be politically popular, because the risk reduction gains will be opaque and highly uncertain. Balancing trade-offs between short-term and long-term goals is a difficult dilemma in determining an acceptable level of flood risk.

Related to such goal-setting, a dilemma also exists with corresponding requirements for investment and capacity development. While flood response capacity will undoubtedly increase as overall development progresses, to keep pace with increasing exposure, an extra pace of capacity development is needed. Yet who will pay for the extra pace of capacity development that will be required to stabilize the risk or even reduce it? What is the right balance between structural and nonstructural measures, and between government and market finances?

### 2.3 Coping with Changing Climate and Uncertainty

The third fundamental dilemma comes with the looming potential climate change impact, and with it, critical uncertainties about the patterns of future flood regimes (IPCC 2011). Planning and investment in flood protection infrastructures—such as dams and dykes—depend on predicting future climate variability. But climate change brings inherent unpredictability of future flood hazard patterns, adding a profound uncertainty for devising flood prevention and mitigation methods and investments. The climate change dilemma requires long-term planning and resolving a series of perplexing climate change uncertainties.

On a global scale, the Intergovernmental Panel on Climate Change (IPCC) has confirmed that climate change is now altering the predictability, intensity, and geographical distribution of many weather-related hazards through increased intensity of the water cycle and glacial melt and sea level rise (UNISDR 2009; IPCC 2011). At a national and regional scale, impacts of climate change on flood hazards are even more uncertain, while global trends seem to be moving towards an increasing frequency and intensity of extreme events (Milly et al. 2002; UNISDR 2009). The average temperature in the Yangtze delta region, for example, is predicted to increase by between 2.3 and 3.3°C by 2050 (NDRC 2007). This significant change in temperature is expected to lead to an array of changes in precipitation patterns, sea level rise, and coastal storm surges (Harvey, Evans et al. 2009).

From the perspective of human-environment interactions in coupled social-ecological systems, these dilemmas are all interlinked and characterized by great uncertainties, dynamic feedbacks, threshold effects, and nonlinear changes (Liu et al. 2007). They are fundamentally dilemmas between managing specific resilience (to floods) versus building a greater general resilience (Walker et al. 2004; Folke et al. 2010). These basic dilemmas place flood risk management decisions firmly in the domain of fundamental challenges to the governance of complex adaptive systems and sustainability, where coordination, cooperation, and social relations are essential

areas that demand innovation. With these dilemmas in mind, the next section discusses some key factors for future flood risk management, before outlining scenarios of plausible pathways.

## 3 Key Factors for Future Flood Risk Management

The looming climate change impacts and the rapidly changing socioeconomic conditions in China raise serious questions relating to future increases in flood risk. How will flood risk change in the coming decades, what number and level of flood events can we anticipate and prepare for? What policy interventions are available? To what extent will floods be a risk to China's long-term sustainable development? A complex array of factors shape and impact these issues.

Figure 1 is a schematic conceptual model of flood risk in the context of climate change and rapid socioeconomic transition. The key factors involve: (1) the major drivers, as well as the critical uncertainties associated with these drivers and their interactions; (2) the dynamics of vulnerability as determined by the covariance between exposure and response capacity that involves short-term coping and long-term adaptive capacity; and (3) the flood management system with both structural and nonstructural measures.

The interaction of all these factors and processes determines the dynamic pattern and change of flood risks and their impacts on society. Many have illustrated clearly the interactive nature of flood events and vulnerability in the context of a coupled human-environment system. Diverse drivers—natural, human, and technical—act as pressure or multiple stresses on the flood risk system, leading to dynamic changes of the control variables that affect and reshape both the pattern of hazard and the system's vulnerability to floods. The dynamics of vulnerability cannot be explained solely either by exposure (for example, population growth and intensification of economic activities) or response capacity (including both short-term coping and long-term adaptive capacities), but are the result of interactive change of both, or the covariance between them (Han 2011).

The key drivers for future flood risks in China are rapid socioeconomic transition, climate change, and the flood defense system itself. While the relative importance of these drivers will vary across river basins, they all are expected to experience major changes in the coming decades. The most challenging drivers for policy and decision makers are those associated with the highest levels of both risk importance and uncertainty, for example, potential climate change.

There is a general linkage between development stage and the pattern of losses from natural disasters. It is often the case that vulnerability tends to rise faster during the phase of transition (Sylves and Kershaw 2004). China today is in the midst of rapid urbanization and industrialization, which will almost certainly continue to increase human exposure to



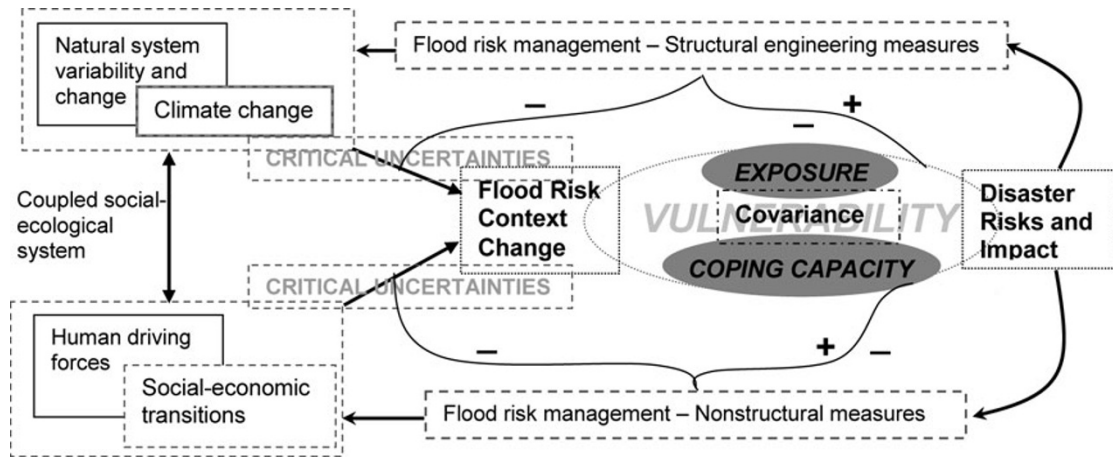


Figure 1. Conceptual model of flood risk in the context of climate change and rapid socioeconomic transition

floods. Rapid urbanization, for example, acts as both pathway and receptor in terms of increasing flood risk. As a pathway, urban expansion increases the proportion of the impermeable surfaces and intensifies runoff. The general trend of current urban development decreases storage and drainage capacity for storm water, and heightens the vulnerability of cities to floods and waterlogging (Shi et al. 2005; Harvey, Evans et al. 2009).

In relation to the dynamics of vulnerability, the impact surrounding uncertainties arising from the changing socioeconomic transitions lies in whether and to what extent the growth of response capacity can match or exceed the increase in exposure (Kundzewicz and Menzel 2003). Examined globally, societal change and economic development are the chief culprits for increasing losses. If the current trends continue, global disaster losses will continue to outpace average economic growth (Bouwer et al. 2007).

In the coming decades, the transformation of the flood management system in China, spurred by ongoing institutional shifts, is a critical process that will determine both the direction and pace of flood response capacity change. The critical uncertainties in this respect reside not only with leadership and investment, but also in capacity development at all levels.

China's waterscape has been profoundly human-transformed and the transformation continues with massive water engineering projects such as the Three Gorges Dam and the ongoing South-North Water Transfer. From a system perspective, these transformations will continue to trigger new feedbacks that change the dynamics of the hydrological regimes, which in turn interact with the changing climate and social economic conditions to set the basic parameters for future flood risks in China. Integrating the above system dynamics from the interactions between climate and socioeconomic change with uncertainties to form scenarios is a key for robust, flexible, and sustainable risk reduction in the future (Schanze 2009).

#### 4 Pathways for the Future—Scenarios

With growing realization of the limited predictability of complex adaptive systems, scenarios are gaining recognition as a useful way for examining future changes. A series of recent scenario-based future risk studies have all confirmed that losses from weather-related disasters are projected to increase, due to a combination of the increasing exposure of people and assets and expected changes in the global climate. In the Netherlands, Bouwer, Bubeck, and Aerts (2010) found that due to socioeconomic change alone, annual expected losses may increase by between 35 and 172 percent by 2040, as compared with a baseline situation in 2000. If no additional measures are taken to reduce flood probabilities or consequences, by 2040 a combination of climate and socioeconomic changes may increase expected losses by between 96 and 719 percent. In the United Kingdom, the Flood Foresight project concluded that expected annual flood damages may increase twentyfold by the 2080s if flood risk management policy were to remain as it is at present (Evans et al. 2004; Hall, Sayers, and Dawson 2005). In Japan, Ikeda, Sato, and Fukuzono (2008) developed various flood risk scenarios in their search for resilient social systems against flood disasters.

In China, similar research is currently under-way in the Taihu (Tai Lake) basin<sup>1</sup> through a China-UK scientific cooperation project initiated in late 2006, which adopted the UK Foresight Project scenario approach (Harvey, Evans et al. 2009). While uncertainties exist in all the scenarios, given China's current development trend, there is little doubt that China's future flood losses will increase. This is not, however, to say that China's vulnerability to flood must also increase. The future state of flood risks in China will not only be influenced by critical uncertainties within the key drivers (for example, the speed and scale of climate and socioeconomic changes) (see Figure 1), but also by human choices that China makes today and along the way. Those choices will largely

determine the pathway through which China's flood risk management system will evolve.

To highlight the different pathways, three plausible future flood risk management scenarios are outlined below. The underlying logic for constructing the scenarios is the priority-setting on dealing with the trade-offs between flood risk reduction and economic development. In the first scenario, China maximizes economic development while continuing to deal with floods largely through engineering approaches. In the second scenario, China prioritizes flood vulnerability reduction by developing and enforcing strict floodplain land-use regulations to limit and control floodplain development. The third scenario outlines a pathway of "living with floods" in which building resilience is achieved through embracing and internalizing, rather than controlling, variability and uncertainty in balancing flood risk reduction and economic development.

#### 4.1 Controlling Floods—Continuation of the Engineering Approach

This is the more or less "business as usual" scenario in which China maximizes economic development while it continues its massive investment in structural measures to control floods. In the short term, economic gains and a technocratic bias will very likely make this pathway irresistible. But in the long term, the result of this pathway will lead China to be increasingly locked into a highly rigid system vulnerable to catastrophic floods, a likely "building up for disaster" scenario.

Over a span of more than half a century since 1949, China has constructed a massive flood control structure system, including more than 85,000 reservoirs of various sizes,<sup>ii</sup> a total of 286,900 km of dykes/levees of various standards,<sup>iii</sup> and close to 100 designated flood detention and retention (storage) zones with a total area of 35,000 km<sup>2</sup> and a total volume of 103 billion m<sup>3</sup>. Together, these measures form an extensive and effective flood defense system that has played a crucial role in flood control in China, reducing the annual inundation area by about 70 percent (as compared with that of 1949) and reducing loss of life dramatically. In the 1950s, the average annual casualties due to floods in China were 8976; this number was reduced to 1507 in the first decade of the twenty-first century (Cheng 2008).

While engineering protection has reduced the total area and frequency of inundation, the economic losses have grown

enormously. Flood-related damage (yuan per hectare) has increased from 2190 in the 1960s to 12,120 in the 1980s and more than 20,000 in the 1990s on a national average. In rapidly developed areas such as the Tai Lake basin in the Yangtze delta, it has increased from 5565 in the 1960s to more than 30,000 in the 1980s (Shi and Pan 1997).

While structural approaches to flood control are essential to reduce flood losses, they have now reached a point where further expansion has become largely unsustainable. First, the "dyke syndrome" or the "dyke effect" (that is, dyke protection induces further development of floodplains that result in further demand for higher dykes) has been increasingly recognized as a driver for the erosion of long-term flood resilience of flood-prone human-environment systems. This has resulted in a continuously worsening discharge and flood level relationship.

Second, the cost-effectiveness of raising dykes/levees has been limited by economic, technological, and environmental constraints. Table 1 shows the investment feasibility calculated by the Institute of Water and Hydropower Research under the Ministry of Water Resources of China. It is extremely difficult to achieve the cost-effectiveness that is required (Xiang 2003).

Third, the existing flood control structures require tremendous investment in quality assurance and maintenance. More than one-third of the 85,000 reservoirs in China now require serious repairs.<sup>iv</sup> The levee systems along the major rivers are the result of centuries of construction, with extremely mixed quality and serious defects. Since 1998, more than 30 billion yuan have been invested in the levees in the middle and lower Yangtze River alone. Most of the investment has been in repair and infrastructure strengthening (Xiang 2003; Cheng 2006).

Lastly, China is running out of places to construct major water infrastructures. With the completion of the Three Gorges Dam on the Yangtze River, the Xiaolangdi Dam on the Yellow River, the Feilaixia Dam on the Pearl River, and the Nierji Dam on the Nen River in the Northeast, China has now basically run out of possible sites for major water control engineering constructions. In addition, many other factors (such as resettlement and migration and ecological impacts) are now raising heightened concerns about new dam construction.

If China cannot break away from the current heavy reliance on its water engineering approach to flood control, one plausible future state of its flood risk system is an increasingly rigid system in which major investment is locked

**Table 1. Feasibility of flood loss reduction by raising levee protection standards**

Current annual average river flood losses (billion yuan)	Loss reduction (%)	Loss reduction benefit (billion yuan)	Investment required for feasible engineering construction (billion yuan)
25	10	2.5	<30
	30	7.5	<90
	50	12.5	<150

Source: Xiang 2003.

into the vicious circle of increasing and maintaining the protection standard of the dyke/levee system. At the same time, the natural flood carrying capacity of the rivers as well as the riverine ecosystems will remain in continuous decline, and waterlogging in cities will become intractable.

While it sounds highly undesirable, this scenario is not only plausible but highly likely. This is the least-resisted pathway in the existing system because it simply requires doing business more or less as usual. In addition, compared to many developed countries, the standard of the flood control structures in China still has much catching up to do. For example, while Japan and China share a very similar percentage in population and assets on the floodplains, most cities in Japan are protected for 500- to 1000-year floods whereas most of the cities in China currently are only protected for 20- to 50-year floods. Furthermore, controlling floods is politically and socially much more straightforward than dealing with vulnerability reduction. Last but not least, many nested interests or “systemic institutional inertia” resist transformative changes (Ostrom 2004, 2007).

#### 4.2 Reducing Vulnerability—Strict Regulation of the Floodplains

This is a scenario in which China prioritizes flood risk reduction and attempts to reverse the trend of increasing economic losses to floods by interfering and shaping developments on its floodplains. While a range of floodplain management options is available and need to be explored in China to strengthen the virtually nonexistent nonstructural measures for flood risk reduction, the biggest challenge for this pathway is how far it can go without interfering with economic development. Given China’s extremely high dependence on its floodplains, a pathway that prioritizes flood risk reduction by limiting economic development will almost certainly encounter tremendous difficulties.

Floodplain management for flood risk reduction is a particularly weak component in flood management in China. There are still many win-win solutions where integrative floodplain management can achieve both economic development and flood vulnerability reduction. Table 2 shows some initial results of the future flood risk scenario study in the Tai Lake basin, with a focus on the scope of risk reduction by careful land-use planning (Wang, Cheng, and Yu 2010). In all of the three scenarios they have analyzed—socioeconomic change only; climate change only; and combined impacts of socioeconomic and climate change—there is significant

scope of potential flood loss reduction through careful risk mitigation-oriented land-use planning, which is nonexistent at present. Yet, in all three scenarios, even with careful land-use planning, expected annual flood losses will continue to increase, ranging from 3.64 to 8.01 billion yuan per year by 2050.<sup>v</sup>

The positive results of this pathway would push China towards a more balanced approach between structural and nonstructural measures for flood risk management. But reversing the trend of increasing economic losses to floods in the future without major interference with the current trend of development intensification in the floodplains, both urbanization and industrialization, is highly unlikely.

#### 4.3 Building Resilience—Living with Floods

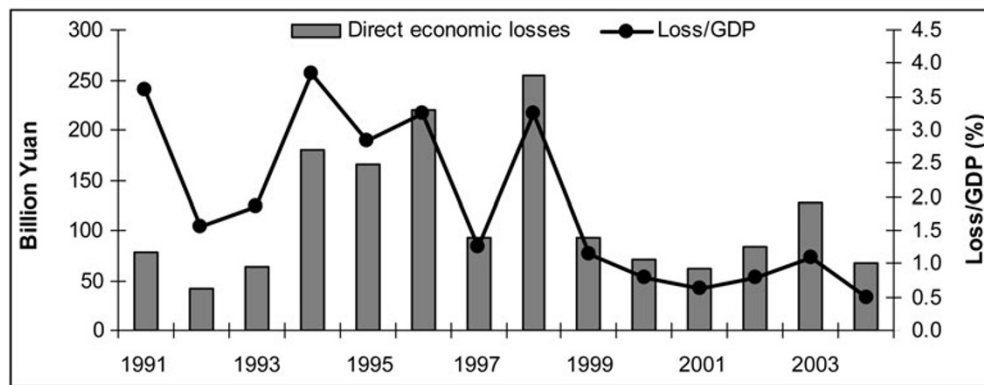
The third potential pathway incorporates components from the two previous scenarios and rests on a series of changes that embrace variability and uncertainties, thus moving towards a strategy of building resilience and living with floods. Many regional flood studies have identified the need to break the feedback loops that have resulted in increasingly fragile and rigid systems with continuously declining capacity in coping with flood and waterlogging. Resilience strategies, such as the “space for water” program to regain the system’s natural flood adjustment capacity, are essential for achieving the sustainability of flood risk management in the future.

In this scenario, the current flood management institutional shift in China takes strong root in the coming years. China moves to adopt a resilience flood risk management strategy that seeks to restore the feedbacks required for a resilient and adaptable flood risk system in the future. A series of principal changes are critical for this scenario. First, the objective in flood risk management is not solely to reduce flood losses but to ensure the good functioning of human-environment systems on the floodplains in terms of the overall benefits from human use and ecosystem services and functions, taking into account risks and uncertainties associated with flooding (Green 2010). Risk management focuses not only on flood losses, but on anticipating the “threshold” or “boundary” losses that could fundamentally undermine the sustainability of the system. In this perspective, the absolute number of direct flood economic losses may not be as important as the ratio of such losses to GDP, since the latter can serve as a boundary or threshold variable that must be managed. Figure 2 shows the direct economic losses and their

**Table 2. Expected future flood risks in the Tai Lake basin and benefit of land-use planning**

Scenarios		2050– Socioeconomic change only	2050– Climate change only	2050– Socioeconomic and climate change
Expected annual damage (billion yuan)	Without land-use planning	6.69	7.14	13.23
	With land-use planning	3.95	3.64	8.01
Benefits of land-use planning (billion yuan/year)		2.75	3.50	5.23

Source: Wang, Cheng, and Yu 2010.



**Figure 2. Direct economic losses due to floods and their ratio to GDP in China: 1991–2004**

Source: Yang 2005.

corresponding ratio to GDP in China from 1991 to 2004. It is clear that while the two are certainly correlated, their trends can be different depending on economic (GDP) development. For instance, while the direct economic losses in 1991 were roughly the same as in 2002, the loss to GDP ratio was significantly lower in 2002. The losses in 2002 were much less of a disturbance to the system than those in 1991.

In the near future, China could focus on two specific goals in this respect. One is to aim for a continued reduction in the loss of life due to floods. With continued socioeconomic development and improvement of general well-being, excessive loss of life due to floods will be increasingly unacceptable, socially and politically.<sup>vi</sup> The other goal should be to lower the ratio of flood economic loss to GDP, which on average stands around 1 percent in the early twenty-first century in China, considerably higher than that in most flood-prone developed countries such as the United States (average ratio 0.03 percent) or Japan (0.2 percent) (Xiang 2003).

Second, effective flood management strategies are based on experimenting and learning to live with floods; land-use adaptation is essential (Klijn, van Buuren, and van Rooij 2004). A full range of floodplain management tools can and should be used to address the flooding problems in China, but the combination and integrated application of those tools will vary among places and communities. Their effectiveness will have to be assessed locally (White 1945, 1974, 1994). Since 1998, the implementation of the “space for water” program in China has encountered tremendous difficulties, partly due to the strict and inflexible top-down scheme that overlooks local dynamics and regional variations.

Third, “controlled flooding” can be applied innovatively as a central strategy to deal with and embrace natural variability and uncertainty. It seeks to manage floods not only as hazards but also as a resource. Controlled flooding seeks to allow places to be flooded when there is excessive water but is flooding by design in terms of locations and sequences. It is a way to accommodate and retain the natural river dynamics and, at the same time, to minimize flood losses and maximize the benefit of natural floods. In the coming decade, major investment can be made to modify and readjust the

existing massive flood defense structures so they are adapted from flood control to controlled flooding. The designated flood detention and retention areas (with a total area of about 5 percent of the flood-prone areas) would be the priority areas to initiate such experiments. One critical enabling condition to make the controlled flooding approach plausible is the rapid technological advancement in recent decades in flood forecasting, real-time monitoring, and transformative changes in communication technology (White 1998).

While a resilience flood risk management approach is possible, implementation of such a strategy often is beset with major socioeconomic dilemmas, such as balancing and accepting major investment in the short term while seeing benefits only in the long term. Shifting the short-term, small-scale rationality to the long-term and large-scale rationality that a resilience strategy requires is not only a challenge for Chinese society, but globally a major obstacle for the pursuit of sustainability (Klijn, van Buuren, and van Rooij 2004; Turner 2010). As illustrated by the Dongting Lake case (Han 2011), or the Poyang Lake case (Shankman, Davis, and Leeuw 2009) and Tai Lake (Taihu) case (Harvey, Thorne et al. 2009), a resilience strategy requires many trade-offs, each of which embodies a range of difficult social, economic, and political issues including investment, compensation, social justice and social stability, poverty reduction, ecosystem services, and biodiversity.

Looking into future flood risks in China, a broader approach is needed, which integrates comprehensively the vulnerability components and aims for building resilience. Until that is done, the “dyke syndrome” will remain and the vicious circle of “higher dyke—more development—even higher dyke” will continue. Ultimately, it is a hard choice to make between less return and more resilient and more short-term gains and less resilient in the long run. So far, few modern societies have chosen the resilience path. To do so requires nothing less than a paradigm shift to embrace rather than control and eliminate variability and uncertainty. That requires fundamental change in the way we perceive the world, what we believe, and the ways we act (Holling 1996, 2001).



## 5 Conclusions

By outlining three fundamental dilemmas and three plausible pathways for managing future flood risk in China, this article concludes:

As the development on floodplains in China continues and intensifies in the coming decades, climate change will very likely increase both the intensity and the frequency of extreme weather events. Accordingly, China will need to learn to live with an increasing vulnerability to flood risk in the foreseeable future. To reduce human vulnerability to floods, multiple pathways exist but all involve difficult trade-offs. Hard choices are inevitable and inescapable.

China needs a new flood management strategy—one that incorporates vulnerability reduction and resilience building. Compared with the traditional engineering approach, a resilience approach requires not only changing the focus from modifying flood hazard events to reducing vulnerability. But it is also essential to embrace and internalize variability and uncertainty in decision making. The latter is essential for changing the management bias from community preparedness achieving full protection or zero flood risk. While vulnerability reduction must be integrated into overall development planning, society will always be vulnerable as long as people live in and develop floodplains.

A resilience strategy for managing flood risk thus requires human adjustment to flood, but not an approach aiming for full protection and control but for adapting human uses of floodplains, integrating, and experimenting with a wide range of flood risk management options. In this way, a reasonably dynamic balance, while not perfect, can be achieved between exposure and response capacity, and flood risk can be contained at a level judged to be socially and economically acceptable.

While a resilience strategy embodies a wide range of opportunities for long-term sustainable flood risk prevention and mitigation, it also raises major challenges. China faces major dilemmas in managing its future flood risks. Trade-offs between economic development and flood vulnerability reduction and between cooperation and tensions across diverse actors and scales cannot be escaped.

Floods are part of Chinese culture, and for many in the floodplains a way of life. Moving from flood control to controlled flooding is a strategic choice towards living with floods in its true meaning. It requires a broad flood risk management approach that is centered on vulnerability reduction and resilience building of the social-ecological system within which the overall goal of sustainability is considered paramount and overall well-being is pursued.

An effective flood risk strategy will only emerge as a result of social learning and innovation and through human interactions with the flood risk system. Embracing variability and uncertainty will be the departure point. Given the past thirty years of transformative changes in the country, China may be a place where such a policy experiment and innovation are not only timely but also embraced.

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## Notes

- i Taihu (Tai Lake) is the third largest fresh water body in China, with an area of over 2000 km<sup>2</sup>. The drainage basin of the Tai Lake covers 36,985 km<sup>2</sup>, including some of the most economically developed areas in the delta region of the Yangtze River.
- ii In 1949, China had only six large reservoirs. The 42,000 km levees were in poor condition.
- iii In comparison, this number in the United States is about 40,000 km. In Japan it is less than 10,000 km, in the Netherlands it is about 4800 km, and in India 20,000 km.
- iv According to the Ministry of Water Resources, there were 30,413 (36 percent of the total) “sick and dangerous” reservoirs in China in 2009: of these 143 were large reservoirs, and 1118 were medium-sized reservoirs. These reservoirs now present a severe source of flooding risks threatening hundreds of millions of people and huge areas of cropland.
- v Current annual average flood economic losses amount to less than 2 billion yuan in the Taihu basin; in the 1990s the annual average flood economic losses were around 70 billion yuan nationwide (Xiang 2003).
- vi The annual average loss of life due to floods in China is still above 2000 people.

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